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We have made progress in defining the apparatus which will be constructed to investigate thermionic cooling. The Nb-oxygen implanted electrode has been investigated using photoemission. A Cs source compatible with the cantilever mount has been demonstrated. A preliminary design of the cell to be used to measure the cooling has been made.



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TECHNICAL PERFORMANCE REPORT

TO

OFFICE OF NAVAL RESEARCH

for a program in

# THERMIONIC COOLING DEVICES

under

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## Introduction

In this program, we propose to investigate the use of thermionic cooling. The basic approach requires development of low work function surfaces with a controllable gap between them. We will use Cs-coated Nb films deposited on opposing surfaces of a micromechanical silicon structure to test the relationships between emission current and fields and gaps. The goal is to identify unambiguous signatures of thermionic emission, and to demonstrate the feasibility of thermionic emission for cooling applications.

## Progress

The approach to our final goals is based on several parallel thrusts:

1) A **low work function surface** is important for enhancing thermionic emission relative to other tunneling-based ejection processes. In our project, we have selected Cs-coated, O-implanted Nb films because of some promising research elsewhere indicating the possibility of reduced work function at room temperatures.

   Progress so far has been on experimental measurements of sample surfaces using XPS facilities available at the Stanford Synchrotron Research Lab. The goal of this preliminary work was to study the relationship between work function and the controllable parameters of surface preparation, namely the parameters of O-implantation (energy and dose), the Nb surface preparation (Ar sputtering, heating time and temperature), and Cs coating parameters (total exposure, advantages of cyclic exposure/evaporation)

   XPS measurements allow determination of the work function of the surface after various sample treatments have been carried out. Using these experiments, we have made a series of determinations.

   First, we have found no correlation between the dose or energy of O implantation and work function reductions. This is perhaps not surprising, because the O concentration on the Nb surface due to atmospheric O exposure and native oxide formation far exceeds the exposure due to implantation. As a result, the O present on or near the surface in all of our samples was probably very much the same, independent of implantation parameters.

   Second, we have found that sample heating is important for surface preparation, but that heating to temperatures of 200-300C is sufficient to achieve the lowest overall work function values. This is probably an indication that the annealing is effectively removing physisorbed surface contamination, but that it is probably not substantially altering the structure of the native oxide on the surface of the Nb. Finally, we have found relationships between Cs exposure and work function that indicate the possibility of low work function for Cs coverages near 1/3 of a

monolayer, and eventual convergence to the work function for bulk Cs for doses corresponding to many monolayers. The data near 1/3 of a monolayer is not very reliable, because small exposures were difficult to control in the XPS apparatus, and the experiments were difficult to repeat. We did observe work functions as low as 0.8 eV, which is a very promising result at this stage of our research. When we have the final apparatus assembled for measurements with controlled gaps between electrodes, we will also have better control over dosing, and plan to carry out more extensive experiments at low Cs coverages.

2) A **large electric field** needs to be created and controlled. To minimize the power consumption, we propose to create the large electric field by positioning a second electrode 10-50 nm from the emitting surface and applying a moderate voltage (1-100V) between these electrodes. We will utilize silicon micromechanical actuators to position and control the two electrodes, based on architectures for micromachined tunneling sensors available in our group.

   Progress in this area has been focused on construction of micromechanical test structures with Nb electrodes. From the experimental results discussed above, we do not plan to have O-implantation carried out on these films, so we are proceeding with fabrication of devices based only on Nb films. Cleanroom training has been completed for the PhD student responsible for this work, and wafers have been started down the fabrication sequence.

   Other progress has been directed towards design, procurement, and construction of a vacuum chamber for the experiments. At this point, a turbomolecular-pumped vacuum system has been ordered, and a bell jar for the experimental chamber has been received. Orders have been placed for Cs sources, vacuum heating elements, electrical feedthrough, and other instrumental fixtures. A particular concern has been design of a modular sample mounting arrangement which would allow sample replacement yet withstand the heating required for Nd film preparation. Most of this design has been completed at this time, and we expect to begin final chamber assembly early in the fall quarter.

   With the fabrication of devices and chamber assembly both underway, we expect to begin measurements on our samples in our chamber in the late fall.

**Summary**

To summarize, we have completed a series of experiments to determine the parameters for Nb film preparation. Using these experiments, we have determined that O implantation is not critical, and that sample heating to 300C is important for surface preparation. We are preparing a vacuum system and some micromachined samples for experiments. And, we expect to be in a position to begin our tests on micromechanical devices with controlled electrode gaps in the late fall.